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EXPERIMENTAL INVESTIGATION AND CFD ANALYSIS OF A MULTI-CYLINDER FOUR STROKE SI ENGINE EXHAUST MANIFOLD FOR OPTIMAL GEOMETRY TO REDUCE BACKPRESSURE AND TO IMPROVE FUEL EFFICIENCY

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ABSTRACT

In internal combustion engines, exhaust manifold plays a vital role in the improvement of fuel consumption of the engine. A good conditioned exhaust manifold increases the performance of the engine. The work is focused on improving the fuel consumption, by reducing the backpressure in the exhaust manifold, experimentally and computationally. This work comprehensively analyzes eight different models of exhaust manifold and concluded the best possible design for least fuel consumption. CFD is the current trend on automotive field in reducing the cost effect for analysis of various models on the basis of fluid flow. A multi-cylinder Maruti - Suzuki Wagon-R engine with maximum speed of 1500 rpm is taken for the analysis. The load and performance test is conducted. From the experiment backpressure and exhaust temperatures are measured. The mass flow rate and velocities are calculated. Flow through the exhaust manifold is analyzed using commercially available software with mass flow rate and pressure as boundary conditions. The results obtained by CFD are compared with experimental values and found to be closely matching.

For comparison, experimental and computational values of backpressure and exhaust velocity are plotted against corresponding experimental values at all loading conditions. The decrease in backpressure and increase in velocities are shown using pressure contour and velocity contour.

KEYWORDS: CFD, Exhaust Manifold, Backpressure, Exhaust Velocity, Fuel Efficiency

INTRODUCTION

While developing an IC engine, it is required to take in consideration all the parameters affecting the engines design and performance. There are a large number of parameters, so it becomes difficult to account them while designing an engine. So it is very difficult to design engine parts optimally by only theoretical or CFD analysis because it is almost impossible to replicate the actual phenomenon in model due to involvement of such a huge number of variables. For example, exactly same part operated under exactly same operating conditions could give drastically different results at slightly different atmospheric temperature. Thus, it is necessary to investigate engine performance related design parameters experimentally and compare with CFD results.

In any multi-cylinder IC engine, an exhaust manifold (also known as header) collects the exhaust gases from multiple cylinders into one pipe. This header is connected to these cylinders through heads. It is attached downstream of

the engine and is major part in multi-cylinder engines where there are multiple exhaust streams that have to be collected into a single pipe. Exhaust gases comes out of this header as a single stream of hot exhaust gases through single outlet.

Exhaustive work has taken place already in this field. Scheeringa et al studied analysis of Liquid cooled exhaust manifold using CFD. He to improve the fundamental understandings of manifold operation obtained detailed information of flow property distributions and heat transfer. He to investigate the parametric effects of operating conditions and geometry on the performance of manifolds performed a number of computations. Deger et al did CFD-FE-Analysis for the Exhaust Manifold of a Diesel Engine aiming to determine specific temperature and pressure distributions. The fluid flow and the heat transfer through the exhaust manifold were computed correspondingly by CFD analyses including the conjugate heat transfer.

Kulal et al (2013) in his “CFD Analysis and Experimental Verification of Effect of Manifold Geometry on Volumetric Efficiency and Backpressure for Multi-cylinder SI Engine” investigated optimal geometry for exhaust manifold for maximum volumetric efficiency. Kulal et al (2013) in his “Experimental Analysis of Optimal Geometry for Exhaust Manifold for Multi-cylinder SI Engine for Optimum Performance” investigated the effect of attaching a reducer to the outlet of exhaust manifold.

For this analysis seven key engine performance parameters are analyzed for both the applications. For recreational purpose volumetric efficiency should be high because power holds highest preference in this regard. Regarding other parameters scavenging efficiency must be high to ensure good volumetric efficiency thus backpressure must be low and exhaust velocity needs to be high. Obviously higher mechanical efficiency and thermal efficiency must be preferred regardless of application. No matter what are the prices of fuel, the designer always prefers lower B.S.F.C. Now, regarding stoichiometric A: F ratio, A: F ratio holds highest preference theoretically but practically slightly rich A: F ratio is generally required.

For commercial purpose or even domestic purpose the above explained preferences holds good except A: F ratio. Usually designers prefer lower backpressure for commercial purpose due to lower B.S.F.C. and slightly lean A: F ratio for economical operations. The power based approach and efficiency based approach are considered.

MODEL DESCRIPTION

The eight models of exhaust manifold considered for this work are:

- Short Bend Center Exit (SBCE)
- Short Bend Side Exit (SBSE)
- Long Bend Center Exit (LBCE)
- Long Bend Side Exit (LBSE)
- Short Bend Center Exit with Reducer (SBCER)
- Short Bend Side Exit with Reducer (SBSER)
- Long Bend Center Exit with Reducer (LBCER)

- Long Bend Side Exit with Reducer (LBSER)

Header length is 335 mm for all models. ID and OD are 52.48 mm and 60.3 mm respectively for the header. In Short Bend models the bend radius is 48 mm. ID and OD of bend are 35.08 mm and 42.86 mm respectively. Long Bend models have bend radius of 100 mm. ID and OD of outlet of exhaust are 52.48 mm and 60.3 mm respectively for all models. Length of the outlet of exhaust manifold is kept at 220 mm and flange is attached at the end to connect it to exhaust muffler. For models with reducer the reducer length is kept 70 mm its inlet ID is 52.48 mm and outlet ID is 38 mm. The total length of outlet of exhaust manifold is kept at 220 mm.

EXPERIMENTAL SET-UP

The experimental set-up is shown below:

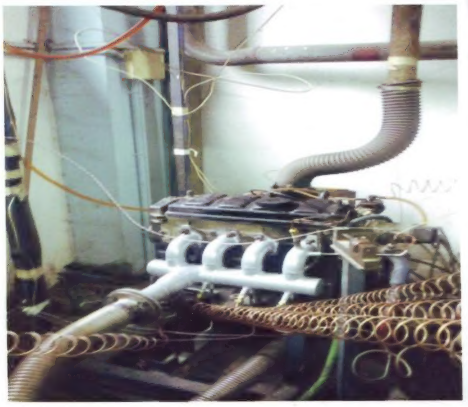

Figure 1: Experimental Set-Up

Table 1: Engine Specifications

Engine	4 Stroke 4 Cylinder SI Engine
Make	Maruti-Suzuki Wagon-R
Calorific Value of Fuel (Gasoline)	45208 KJ/KG-K
Specific Gravity of Fuel	0.7
Bore and Stroke	69.05 mm × 73.40 mm
Swept Volume	1100 cc
Compression Ratio	7.2:1
Dynamometer Constant	2000
Diameter of Orifice	29 mm
Coefficient of Discharge of Orifice	0.65

METHODOLOGY

The experimental values of backpressure, exhaust temperatures are noted down using gauges and temperature sensors and the mass flow rate and velocities are calculated at the inlet and outlet of exhaust manifold. Then, exhaust manifold models are prepared using SOLIDWORKS and analysis is carried out using WORKBENCH 12.0. The inlet mass flow rates and pressure at outlet are considered as boundary conditions. The turbulence model used is k-ε. Turbulence intensity is kept 10%

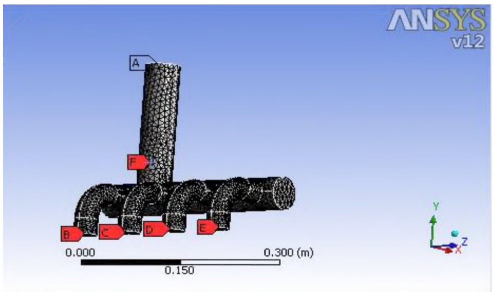

Figure 2: Short Bend Side Exit Meshed Model

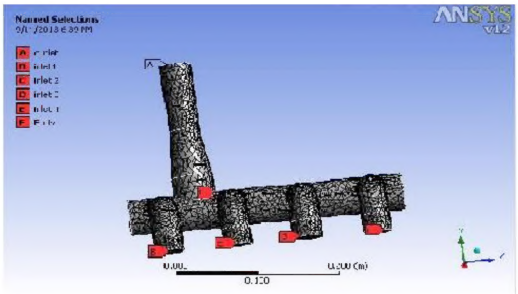

Figure 3: Short Bend Side Exit with Reducer Meshed Model

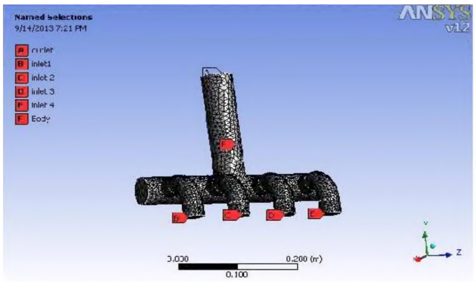

Figure 4: Short Bend Center Exit Meshed Model

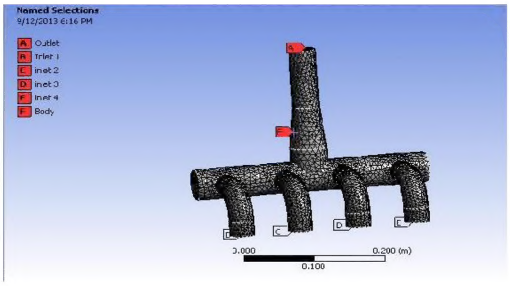

Figure 5: Short Bend Center Exit with Reducer Meshed Model

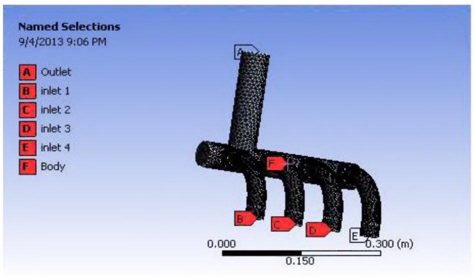

Figure 6: Long Bend Side Exit Meshed Model

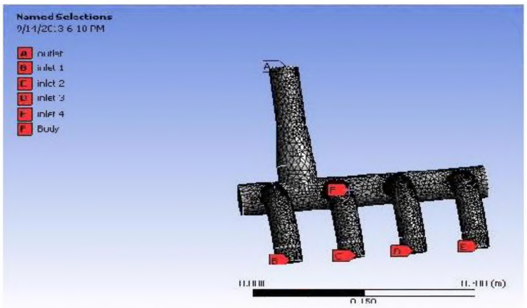

Figure 7: Long Bend Side Exit with Reducer Meshed Model

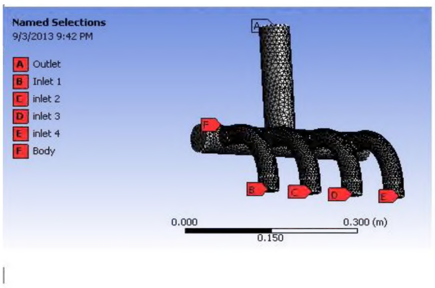

Figure 8: Long Bend Center Exit Meshed Model

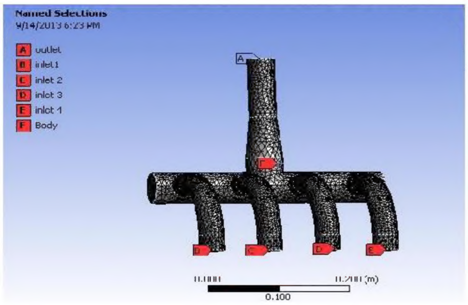

Figure 9: Long Bend Center Exit with Reducer Meshed Model

RESULTS AND DISCUSSIONS

The results obtained by CFD simulations at 2KG loading are shown below. The pressure contours are shown below. Similarly, results are obtained at all six loading conditions.

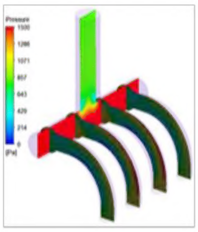

Figure 10: LBCE

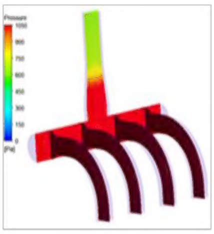

Figure 11: LBCER

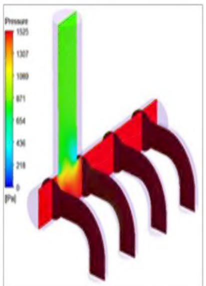

Figure 12: SBSE

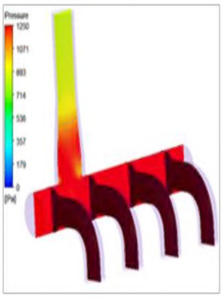

Figure 13: SBSER

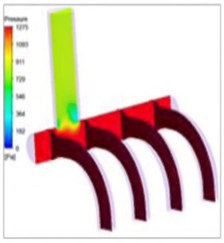

Figure 14: LBSE

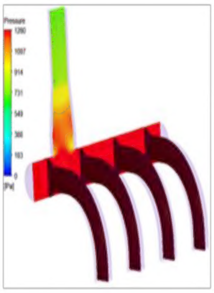

Figure 15: LBSER

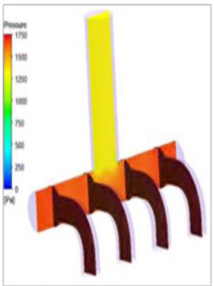

Figure 16: SBCE

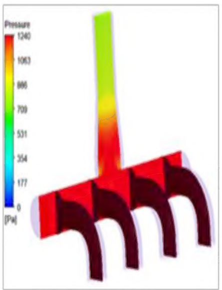

Figure 17: SBCER

Figure 10

The results obtained by CFD simulations at 2KG loading are shown below. The velocity contours are shown below. Similarly, results are obtained at all six loading conditions.

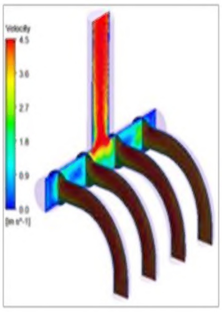

Figure 18: LBCE

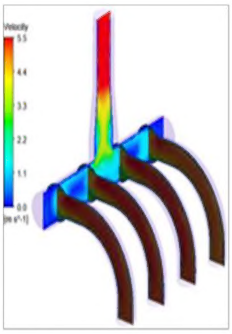

Figure 19: LBCER

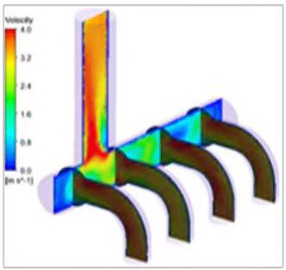

Figure 20: SBSE

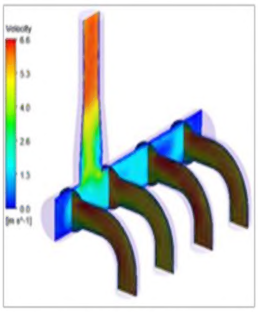

Figure 21: SBSER

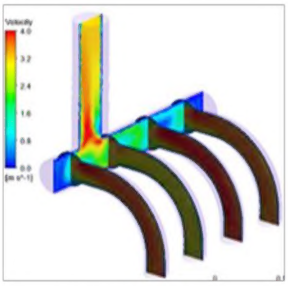

Figure 22: LBSE

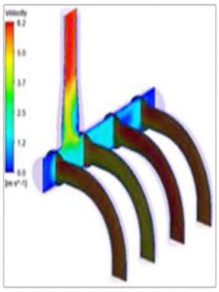

Figure 23: LBSER

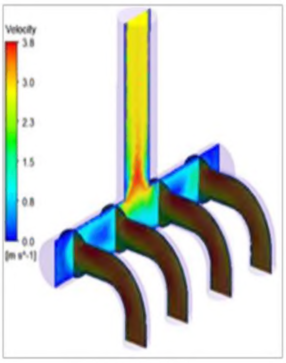

Figure 24: SBCE

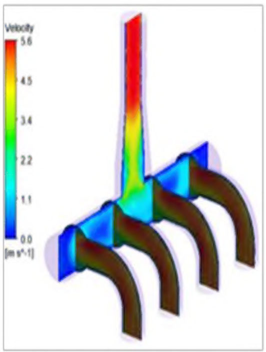

Figure 25: SBCER

Figure 11

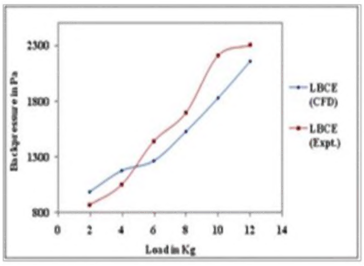

Figure 26: LBCE

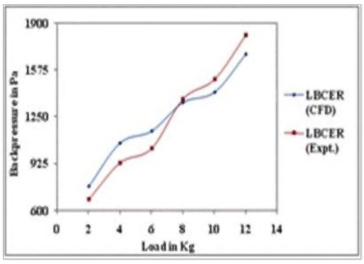

Figure 27: LBCER

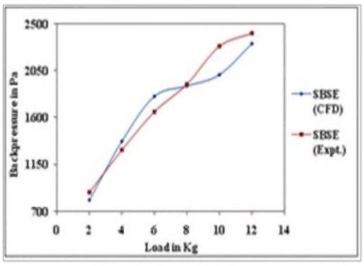

Figure 28: SBSE

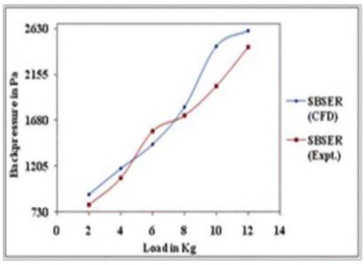

Figure 29: SBSER

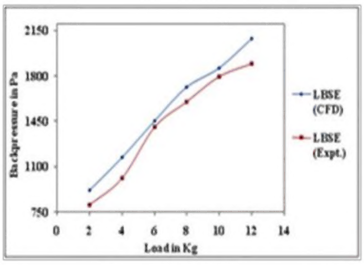

Figure 30: LBSE

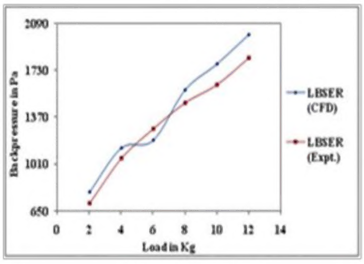

Figure 31: LBSER

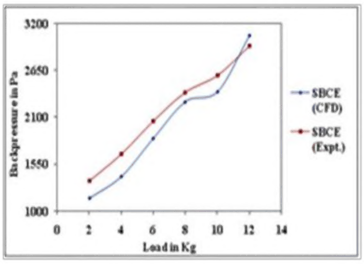

Figure 32: SBCE

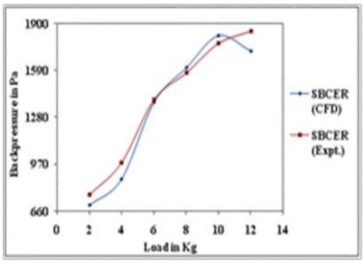

Figure 33: SBCER

Figure 12: Overall Performance Score for Commercial Purpose

CONCLUSIONS

All the tests on exhaust manifold are conducted on four stroke four cylinder engine of Maruti - Suzuki Wagon-R. Experiments are carried out at six different loads keeping speed constant. The findings of the work are enlisted below:

- The minimum backpressures and higher exhaust velocities are achieved by using exhaust manifolds with reducers, thus reducing emissions and which helps in development of emission standards. Reduction in un-burnt fuel inside the chamber results in increased power with less consumption of fuel thereby increasing its fuel efficiency.
- LBCER exhaust manifold gives highest overall performance score of 82.639 for recreational applications. The modification in its geometry by varying its exit position (Centre exit) with reducer and using long bends helps

in increasing the overall performance of engine from recreational application point of view. The cost of mass production of these models is higher than SBSER model due to longer bends.

- LBCER exhaust manifold gives highest overall performance score of 83.36 for commercial applications. The modification in its geometry by varying its exit position (centre exit) with reducer and using long bends helps in increasing the overall performance of engine form commercial application point of view.
- LBSER and SBSER exhaust manifolds are the second best and have overall performance scores of 81.112 and 83.2 for recreational and commercial applications respectively. The advantage of LBCER model can be achieved by using LBSER and SBSER models as these models improve the engine performance considerably. The mass production of SBSER model can be reduced to economic range due to shorter bends.

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